Every day, the Earth receives 1,500 times as much energy from the sun as mankind consumes. A fully solar-powered future of the world’s cities is, therefore, by no means inconceivable. Efficiency measures and ‘secondary’ renewables such as wind and biomass will assist in the energy transition to come, but ultimately, the greatest promise lies in a combination of large-scale solar power plants and small-scale, building-integrated, solar energy uses.

By Richard Perez

WHY?
World energy consumption will have grown by another two thirds by 2050. At the same time, all energy reserves – except renewable energies – are limited, so is nuclear energy, which relies on the conversion of uranium. But climate change is providing the most powerful stimulus for restructuring our energy supplies; CO₂ emissions can be halved by 2050 only if the use of renewables is promoted alongside greater efficiency.

WHAT?
What are the renewable energies sources with a future? Wind power alone could cover mankind’s needs, but this is already approaching the limits in many countries. Biomass should be restricted to uses for which burning processes are essential. This leaves the sun as the main provider of energy; it gives the industrialised states alone 1,500 times more energy than mankind consumes at the moment.

HOW?
The question to be asked about solar energy provision is not whether supply should be centralised or decentralised; the two concepts have to be taken together if requirements are to be met. Energy provision will have to come from renewable sources, in the future even more than now. This means that the buildings we build or refurbish today must be based on a carbon-neutral energy supply from sources such as solar panels, and be provided with adequate storage facilities for heat and electricity.
At present, the total primary energy consumption of the world is of the order of 400 exajoules per year, amounting to a constant power demand of 16 TW. This consumption is not distributed equally, with rich industrialised countries such as the United States and China using almost 22% of the world's energy with only 5% of its population. Growing economic powers such as China and India are rapidly increasing their demand for energy with a combined consumption now exceeding that of the United States, suggesting that the current world distribution of energy is headed for a strong growth. The US Energy Information Agency anticipates that worldwide demand will reach 23 TW by 2030 and trend to 28 by 2050. Over these quarters of the growth is expected to take place in OECD countries, occurring primarily in commercial and transportation sectors.

Unfortunately, such official predictions by national and international agencies also anticipate that the bulk of this growth will be met by coal, with renewable energies playing only a side role. However, a fundamental look at the energy resources of the planet suggests that this business-as-usual outlook may be both short-sighted and unrealistic.

MEETING ENERGY DEMAND

There are two ways to meet worldwide energy demand and its anticipated growth: 1. On the demand side, by acting to reduce, and eventually reverse, the growth rate, using conservation and increasing efficiencies, e.g. by substituting more efficient engines, higher efficiency lighting, better insulation and avoiding unnecessary waste, in a few words, smarter, better and smaller. The McKinsey report on climate change indicates that over 40% of the consumption of major consumers like the United States could be met economically and efficiently. 2. On the supply side, by tapping renewable energies. The available solar energy exceeds the world's energy consumption by a factor of 300. Fossil fuels like oil and coal alone could fulfill our energy needs for another three or four centuries, but would do so at a considerable environmental cost.

RENEWABLE OR FINITE RESOURCES?

The figure on the opposite page compares the one-year potential supply of renewable resources against the finite reserves of conventional energies. Fossil fuels: apart from their environmental impact, Figure 3 suggests that the recent ‘boom-bust’ volatile in oil and gas markets are early symptoms of their finiteness when demand begins to outstrip supply. So as coal, while reserves are vast, they are not infinite and would last at most a few generations if this became the predominant fuel, notwithstanding the environmental impact that would result from such exploitation if new efficient ‘clean coal’ technologies do not fully materialise.

Nuclear energy is not the global warming ‘silver bullet’ claimed by some. Reserves of uranium are large, but they are far from limitless. Setting aside all the long-term environmental and proliferation unknowns associated with this resource, there would simply not be enough nuclear fuel to take over the role of fossil fuels: the rise in the cost of uranium that paralleled, and even exceeded, that of oil from 1998 to 2008 is symptomatic of this reality. Of course this statement would have to be revisited if an acceptable breeder technology or nuclear fusion became deployable. Nevertheless, short of fusion, even with the most speculative uranium reserves scenario and assuming deployment of advanced fast reactors and fuel recycling, the total finite nuclear potential would remain well below the one-year solar energy potential.

The solar resources: it is plainly evident that the magnitude of the solar resource dwarfs any other finite and renewable resources. The yearly, indefinitely renewable supply of solar energy received by the emerging continents alone is more than 30 times larger than the total current planetary reserves of coal and 1,500 times larger than the current planetary energy consumption. The solar resource is well distributed and widely available throughout much of the planet. It is of course more abundant in the tropical belt than it is in the temperate zones; but consider that even such a modest sized, northern, and sometimes cloudy country as Denmark receives a total of nearly 5 TW-year worth of solar energy every year, that is one third of the energy consumption of the entire planet. It is widely believed that deploying solar energy on a massive scale would utilise too much space. Nothing could further from reality: assessing a 30% solar-to-useable energy conversion rate (a target achievable by 2050’s less than one half of one percent of the emergent continent’s area would be sufficient to produce all the projected energy used by the planet. This is an area smaller than the earth’s current total land surface of and much of the urbanised land can be used for solar harnessing with very little visual or operational impact. Consider the city of New York, for instance, arguable, one of the densest energy demand hubs on the planet; together with smart demand-side operational efficiencies, New York City could certainly be solar self-sufficient electrically by 2050 using only 25% of its surface, i.e. the size of its current roof space.

Another interesting point of reference is to contrast solar generation against requirements with hydroelectric artificial lakes. In the United States, for instance, artificial lakes occupy 100,000 square kilometers of flooded land to produce only 7% of the country’s electricity. By contrast, with 30% PV efficiency, under two thirds of that flooded space would be sufficient to produce all the electricity in the US.

Other renewables: how about wind power, hydropower, biomass/biofuels, marine currents, waves, ocean thermal energy conversion (OTEC), geothermal, and tides? First it is worth noting that, with the exception of tides and geothermal, all the renewable resources are second and third-order by-products of incoming solar energy – just as fossil fuels are by-products of solar energy stored in the earth over millions of years. These renewables are, indeed, concentrated forms of solar energy, which makes them more economical to exploit in the short term, especially hydropower. As such they will have an important role to play initially. However, as by-products, their potential is considerably smaller than that of the primary solar resources.

Wind energy could probably satisfy all of the planetary energy requirements and more if ‘smart’ developments in the area of solar technologies (wind, solar bi-
A reality-check check - The growth of the wind and solar industries: a quick look at the direct and indirect solar industries that are fact emerging throughout the world today indicates that the high-profile renewable visions discussed in this article already have a strong head start. Consid-ering the growth of PV, wind, and CSP alone over the last five years and projecting this growth rate in the future indicates that the majority of the new electric generating capacity installed in the world will come from renewable resources in less than 20 years. This success rate may still be suf-ficiently high, given the fossil fuel deple-tion and environmental pressures, but it is already impressive; and sug-gests that when additional countries and decision-makers become aware of the need for a fast transition, a rapid renewable take-off and switch-over is not only in the sky but a viable and rapid change of awareness is taking place here and now. For a long time confined to visionary leaders such as Germany, Denmark or Japan, the drive for renewables that has caught up in the rest of Europe is now gathering momentum in the United States, driven by a new administration. At the same time, China, which became the world’s largest PV producer in 2008, edging Germany out of first place, has just adopted an upward revision of its renewable en-ergy deployment plans, including 100 GW of land-based wind generation by 2020. The main attraction of this decentralised deployment model is that it would result in indigenous, highly-secure, and robust energy pathways. Because of the decentralisation of production, demand management, and storage operation, the failure of any one centralised unit, with built-in-malfunction and alone-operation ca-pability, would be insignificant.

1. Local, decentralised production of solar-generated electricity near points of utilisation – largely using PV, but also wind, taking advantage of available space – particularly space that can be used for solar har-vesting in addition to its primary role like building envelopes, industrial ex-clusion zones, transportation right of ways, etc. The resource is large enough in almost every part of the world to fulfil most needs. How-ever, a considerable technological challenge will be to be addressed because the largest renewable re-sources (solar and wind) are inter-mittent and vary seasonally. Smart, interactive electrical load manage-ment and energy storage technol-ogies will have to undergo a fast development phase.

2. All other extremes are conti-nental and, possibly planetary, super power grids. The basic idea behind this vision is that some places on the planet receive more solar energy than others (subtropical deserts) and that the average solar yield of the entire planet is nearly constant (i.e. it is always sunny somewhere on planet Earth). There are conceptual proposals on the drawing board in both Europe and America consid-ering the types of solar energy deploy-ment. The approach will be to maximize the development of very high volt-age, highly conductive power lines and, more importantly, will neces-sitate a strong and tacit agree-ment between all involved parties and countries to maintain and pro-duce such a network.

The future will likely be a combination of both fully decentralised systems and subcontinental-scale networks with centralised generators. The good news is that the two approaches are not incompatible and could even be complementary. Large corporations and utilities will probably prefer centralised applica-tions because of econom-ies of scale and similarities with the current electric production/distribu-tion system. In this scenario, wind electricity – largely centralised, or semi-centralised by nature – will play a major role initially. Ultimately, the decentralised systems should flourish and prove as technology costs fall and, more importantly, the value and resiliency of on-site generation can be fully captured. As discussed above, the costs of producing clean renewable energy and its value are still largely disconnected entities in the current business environment, al-though this question is already being addressed in some embryonic form via incentives such as feed-in tar-iffs (FITs)14, legislation proposals pat-tended after that of Germany, with highest value given to decentralised solar applications15.

Serving all energy needs from re-newables: because of the univer-sal nature of electricity produced by direct and indirect solar technol-ogies, the great majority of energy demand sectors will be adequately served, albeit with some adaptation/ evolution. Transportation in partic-ular currently relies on fossil liquid fuels. A shift to renewables will re-quire particular attention but the task is not insurmountable: by 2050, ground transport will have become largely electric through in-crease of electric rail-based mass transportation, the advent of all-electric vehicles and plug-in hybrids – e.g. spearheaded by projects such as the U.S. Advanced Vehicle Projects16 designed from the onset to exploit renewable energy – and new concepts such as Per-sonal Transportation Networks. It is also possible to produce fuel, or fuel equivalents, derived from solar/ wind electricity – hydrolysis of hy-drogen being the most familiar. If the most promising, method: this so-called ‘second generation’ biomass should be reserved for the remaining applications that could not easily yield on electricity directly or indirectly, such as air transport and, to a lesser extent, water transport.

HOW MUCH WILL IT COST?

Of course, switching overnight to direct/indirect solar would incur a seemingly impossible large finan-cial burden, a point often raised by detractors of renewable energies. However, a fast-track growth and complete turnover within 50 years will be affordable, especially as both apparent and real costs of conven-tional energies escalate. In the end, what will matter is the value prop-osition offered by solar and re-newables, not the cost. If value exceeds cost, then there is no question that renewables will be the way to go, and many indicators point in that direc-tion. The price we pay in our energy bills today simply does not include all the costs incurred by society: two major costs that are not yet included, as they should be, are the costs as-sociated with the degradation of the environment (chiefly global warm-
energy payback of 3–5 years today and energy pay-back period, these technologies far exceed their construct and install them. With operated under average conditions can be simply expressed in this one

direct solar technologies have an
costly and indirect solar technologies have an energy payback of 3–5 years today and are constantly improving. i.e. when operated under average conditions, these technologies produce more energy in a few years than is used to construct and install them. With operational lifetimes far exceeding their energy pay-back period, these technologies are, in effect, energy breeders capable of powering themselves into growth. Energy payback is a fundamental physical measure of long-term economic viability to societies investing in it. For a monetary translation of this physical reality, let us look at a world-case example: a totally unsubsidised PV installation (the most expensive solar technology today, likely to be 2–3 times cheaper in 20 years) in the north-eastern US region with a modest solar resource valued against current wholesale electricity (a Rock–

TABBED: Primary energy consumption per source and 1995–2005 growth trends for OECD and non–OECD countries

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